Augmented Interaction: Applying the Principles of Augmented Cognition to Human-Technology and Human-Human Interactions

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Abstract. The field of Augmented Cognition (AugCog) has evolved over the past decade from its origins in the Defense Advanced Research Projects Agency (DARPA)-funded research program, emphasizing modulation of closed-loop human-computer interactions within operational environments, to address a broader scope of domains, contexts, and science and technology (S&T) challenges. Among these are challenges related to the underlying theoretical and empirical research questions, as well as the application of advances in the field within contexts such as training and education. This paper summarizes a series of ongoing research and development (R&D) efforts aimed at applying an AugCog-inspired framework to enhance both human-technology and human-human interactions within a variety of training and operational domains.

Keywords: Augmented Cognition, Training, Simulation, Human-Robot Interaction, Adaptive Automation, Neuroscience, Psychophysiological Measures, EEG.

1 Overview

The field of Augmented Cognition (AugCog) has evolved over the past decade from its origins in the Defense Advanced Research Projects Agency (DARPA)-funded Improving Warfighter Information Intake Under Stress (IWIIUS) research program, emphasizing modulation of closed-loop human-computer interactions within operational environments [1, 2], to address a broader scope of domains, contexts, and science and technology (S&T) challenges. Among these are challenges related to the underlying theoretical and empirical research questions, as well as the application of

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advances in the field within contexts such as training and education. The goal of AugCog is to address the inherent limitations of human operators related to cognitive bottlenecks in information processing such as attention, sensory input, WM, and executive function; and emphasizes real-time monitoring of user cognitive state via behavioral and physiological measures to improve performance through adaptive and augmented human computer interfaces [3]. As data-rich environments become increasingly prevalent, the need for intelligent information management to overcome human information processing limitations is likely to increase within a wide variety of domains such as medicine, education, and information analysis. Additionally, while AugCog methodologies have been applied to domains involving teams of humans, the method of augmentation has primarily been focused on physiologically-based modulation of human-technology interaction [4]. Ongoing research and development (R&D) efforts have begun to emphasize transparency and identical elements in human-robot and human-human interactions, supporting seamless integration of multi-agent human-robot teams, and applying AugCog principles to automated modality selection of information exchange among human team members and between human-robot team members. This paper summarizes a series of ongoing research and development R&D efforts aimed at applying an AugCog-inspired framework to enhance both human-technology and human-human interactions across a variety of training and operational domains.

2 AugCog-Inspired Human-Technology Interaction

Interaction design principles and practices are grounded in both theory and research, guided by academic disciplines such as cognitive psychology and engineering, as well as interdisciplinary fields such as Human Computer Interaction (HCI), human factors, and cognitive ergonomics. The application of AugCog-inspired interaction principles presents a unique paradigmatic shift in the design and use of such products within both training and operational domains.

2.1 AugCog-Inspired Virtual Training Environment Design

Vice, Lathan, Lockerd, & Hitt [5] proposed a novel, AugCog-inspired methodology for determining requirements for virtual environment (VE) design using psychophysiological measures to determine which aspects of VE fidelity and specific VE fidelity configurations would have the highest impact on transfer of training (TOT). Initial validation for this Perceptually-informed Virtual Environment (PerceiVE) design methodology has been demonstrated within a series of empirical studies, indicating that psychophysiological response, and in particular event related potentials (ERPs), may provide a more sensitive index than performance-based measures to changes within underlying cognitive processes occurring during training in VEs, and therefore may be better suited than traditional metrics for highlighting critical fidelity requirements to optimize TOT [6,7]. To better understand the implications for transfer to real world task conditions, Vice, Skinner, Berka, Reinerman-Jones, Barber, Pojman, et al.

[8] compared behavioral and neurological response data between a real world perceptual skills training task and its VE counterpart with varying levels of fidelity. Results indicated that the relationship between physiological response to various VE fidelity configurations and physiological response within an equivalent real world task may be modulated not only by visual feature recognition and processing, but also by higher-order cognitive processes, as evidenced by ERP. Understanding how fidelity variations in VE-based tasks lead to the most efficient processing will inform designers as to which components are responsible for the strongest impartation of skills and ultimately optimize transfer of training [9].

Additional simulation-based training applications that are ripe for exploration using this methodology include remotely piloted aircraft (RPA) training and medical modeling and simulation. Medical simulation-based training reduces risks to human subjects and recues the need for cadaveric and live animal models, supporting training and maintenance of psychomotor skills such as tissue and tool manipulation; cognitive skills related to decision making, declarative and procedural knowledge, and situational awareness; and perceptual skills such as visual feature detection and haptic perception. As in other high-risk training environments, it is the common assumption that a positive linear correlation exists between VE fidelity and skills transfer. However, training on seemingly low fidelity training systems such as the Fundamentals of Laparoscopic Surgery (FLS) video box trainer has repeatedly been demonstrated to translate to complex skills such as interoperative surgical performance, and has become a credentialing criterion for many hospitals [10]. Thus, utilizing the PerceiVE methodology to identify medical simulation design requirements may result in optimized skills instruction, enhancing transfer to real-world medical scenarios.

Skinner, Vice, Berka, & Tan [11] expanded upon this concept, proposing a framework for using psychophysiological measures and feedback within interactive training environments to develop a greater understanding of the processes underlying cross-cultural decision-making and methods for training these critical skills; including detection of variations in information processing and cognitive biases that impact decision-making, interaction within explorable environments, and presentation of relevant cues to facilitate immersion and perspective-taking. This framework suggests that, in particular, neurophysiological metrics such as EEG have the potential to provide an objective measure of cognitive processes involved in attention, perception, and decision-making related to information processing biases; and that eyetracking may support recognition and mitigation of such biases via feedforward and feedback scan patterns, highlighting culturally-relevant perceptual biases. Additionally, this framework incorporates the use of interactive virtual training environments capable of dynamically adapting instruction to individuals based on specific biases exhibited, as well as real-time bias assessment and mitigation.

2.2 AugCog-Inspired Human-Robot Interaction

In addition to simulation-based applications, current research and development is seeking to apply a similar methodology within the context of human-robot interaction (HRI). Woods [12] compared the introduction of automation to a human operated task to adding another team member who does not necessarily speak the same language and share the same cultural assumptions. Thus, an interface must act as a bridge or translator between humans and automated systems by providing connections and mappings between related concepts in a manner that is partially transparent to the individual human and robot agents. While significant advances are continually made within the domains of robotics and artificial intelligence (AI), the design of robotic control interfaces lacks a validated and scientifically-grounded methodological approach; and currently interface design tends to be an afterthought following development of unmanned systems, with minimal consideration of design and assessment methodologies relying on measures other than those that are purely behaviorally and ergonomically based.

Significant research and development has been invested into physiological sensor-based robot [13] and prosthetic [14, 15] command and control. The application of AugCog principles would expand on this, using physiological signals to measure cognitive states, classify error patterns, and predict cognitive performance degradation within the context of HRI. Vice, Lockerd, and Lathan [16] proposed an AugCog-based approach to multi-modal interface design and implementation, and research conducted under the IWIIUS program demonstrated the use of multi-modal cues and modality switching as a an effective mitigation technique for UAV operations [2]. In recent years, adaptive interfaces have become increasingly prevalent [17], and more specifically, neuroadaptive interfaces are being developed to change in response to meaningful variations in a human user's cognitive and/or emotional states [18]. However, while psychophysiological methods have been investigated in the realm of Adaptive Automation (AA), the vast majority of this work has been oriented on earlier stages of automation (SOA) involved with information acquisition, information analysis, and diagnostic decision support as opposed to the direct action components of unmanned system control (for review see [19]).

Parasuraman, Bahri, Deaton, Morrison, and Barnes [20] identified five primary categories of AA implementation techniques: 1) critical events, 2) operator performance measurement, 3) operator physiological assessment, 4) modeling, and 5) hybrid methods combining one or more of these techniques. Fidopiastis et al. [21] highlight the fact that of these, operator psychophysiological assessment is the only technique that supports unobtrusive real-time operator internal state monitoring without task interruption. Furthermore, this technique may provide the most direct and objective means for assessing and guiding interaction; the dynamic real-time aspects of this methodology preclude the disruptive influence of subjective self-report instruments and secondary task assessments in complex and highly stressful environments while providing temporal resolution on the order of seconds or milliseconds. Byrne and Parasuraman [22] suggest that psychophysiology has two complementary roles within AA research, including assessment of the effects of different forms of automation and the provision of information about the operator that can be integrated with performance measurement and operator modeling to support automation regulation. The advantages posed by the use of non-invasive psychophysiological measurement as a cueing strategy for AA are substantial. While psychophysiological measures may be thought to be most useful for detecting and preventing cognitive overload, Byrne and Parasuraman [22] have asserted that psychophysiological measures may prove especially useful in the prevention of performance deterioration within underload conditions, which often accompany automation. So-called OOTL (Out Of The Loop) problems have been shown to arise due to human vigilance decrements [23], human complacency [24], and human loss of SA [25]. Thus, as described by Fidopiastis et al. [21], psychophysiologically-based AA has the potential to be applied within high-stress environments in order to alleviate operator workload and fatigue as needed, automating select activities until an operator becomes underloaded and requires additional tasking in order to maintain situation awareness (SA).

The highly structured and quantifiable nature of these measurements also provides a crisp perspective of an operator's cognitive state that can control for individual differences via baseline comparison and minimize the influence of ego and performance bias in risk intensive task / mission sets that require a high degree of confidence as well as technical competence and physical prowess. Fidopiastis et al. [21] highlight the fact that individual differences such as spatial ability and perceived attentional control (PAC) are critical within this context, as demonstrated previously by Chen & Terrence [26].

Parasuraman, Barnes, Cosenzo, and Mulgund [27] specifically demonstrated the effectiveness of AA for supervision of multiple unmanned vehicles. Parasuraman [28] demonstrated the feasibility of matching cardiovascular and cerebral bloodflow-based measures of human mental workload to AA, and more recently, Fidopiastis et al. [21] demonstrated the feasibility of an eye fixation-based workload metric for AA in a simulated robotic control task. Critical to these efforts are the development of reliable measures of cognitive state and performance degradation caused not only by cognitive workload, but also by factors such as fatigue and stress, which may require more sophisticated and sensitive metrics, as well as the integration of various indices. Combining psychophysiological measures with behavioral measures such as validated task battery performance will support the development of hybrid metrics of cognitive function, which amount to more than the sum of their constituent parts, providing more sensitive indices of cognitive state.

Under a current R&D effort our multidisciplinary research team has begun development and validation of a methodology and associated technology tool to support the utilization of multiple, heterogeneous metrics, including operator psychophysiological measures, to drive robotic control interface design and real-time interactions with unmanned systems. This Dynamic Robot Operator Interface Design (DROID) Assessment, Guidance, and Engineering Tool (AGENT) seeks to support instantiation of intelligent sliding autonomy, modality switching, and single versus multi-operator control and feedback offloading. An effective sliding autonomy system should determine the level of individual component autonomy based on maximizing the probability of task or mission accomplishment, taking into account not only operator physical and mental state, but also environmental and task or domain-specific factors. This is critical within the context of military operations in which factors such as rules of engagement, standard operating procedures, and operational tempo may dictate prioritization of tasking and the role of automation, as well as devastating environmental conditions that lie beyond the capabilities and vulnerabilities of human operators.

Finally, as robotic systems increase in complexity beyond anthro-centric limitations to function in such environments, it is equally clear that human cognitive functions are ill suited to do so without the aid of automated modules throughout the spectrum of control.

2.3 Environmental Factors

In addition to incorporating physiological indices of operator state within human-technology interaction design, the context in which such metrics and methodologies are applied must be considered, particularly within military operational environments. A host of factors must be considered beyond cognitive state and information processing limitations, including physical demands on the operator and unique environmental conditions. For example, motion sickness can result from teleoperation tasks, particularly in instances in which the operator is required to teleoperate a robotic asset while in a moving vehicle or on a ship, generating a mismatch between the perceived motion of the unmanned asset and the motion experienced directly by the operator within his or her own environment. AugCog-based systems can be used to gauge the physiological effects of the motion experienced both physically and virtually by the operator. Ideally, a combination of objective and subjective measures could be used to develop validated, multi-dimensional algorithms and constructs to enable effective assessment, prediction, and prevention of motion-induced human performance degradation within a multitude of training and operational environments, including both apparent motion, such as that associated with simulation-based training and teleoperation of remote unmanned vehicles; and actual motion within ground, sea, air, and spaceflight vehicles.

Within the context of naval ship-based operations, ship motion is often a primary contributor to human performance degradation and failures across a wide variety of operational tasks. While motion sickness has been studied extensively, much less research has been dedicated to motion-induced fatigue (e.g., Sopite syndrome symptomology, prevention, effects on performance, and mitigation), and to the complex interactions between motion, fatigue, and stress. Additionally, few studies have explored the constellation of psychophysiological responses associated with motion sickness or the time course of motion sickness, which is non-linear. Neurophysiological metrics have the potential to identify individual differences within a particular task environment, determine metrics that can predict the onset of motion sickness or fatigue, and provide methods for offloading tasks in real-time prior to human performance degradation within the operational environment.

A current effort is being undertaken to design, develop, and validate a Portable Automated Sensor Suite (PASS) Motion-induced User Symptomology Toolkit for Evaluating Readiness (MUSTER) to enable unobtrusive, real-time capture, synchronization, and analysis of environmental, physiological, physical, and subjective measures associated with motion-induced performance degradation within sea-based task environments. This multi-dimensional assessment technology will provide a valuable tool for researchers investigating the effects of motion-induced mishaps, fatigue, and sickness over time, and will also provide a deployable tool for operational use in determining “fitness for duty”. For example, one instantiation of the proposed technology might include a brief set of questions related to motion sickness and fatigue, brief cognitive and psychomotor tests, and the ability to do a rapid physiological sensor reading. Thus, crewmembers could be assessed prior to beginning a shift or prior to conducting high-risk tasks (e.g., on an amphibious vehicle before conducting an amphibious assault) to assess fitness for duty. The embedded algorithms will be developed to flag at-risk individuals, enabling commanding officers to make informed decisions regarding crew shifts and job assignments, and to pull individuals that do not “pass muster” from duty in order to prevent catastrophic performance degradation and errors.

3 AugCog-Inspired Human-Human Interaction

3.1 Cognitive Coupling in Dyads

In addition to modulating human-technology interactions, AugCog principles are beginning to be applied to direct interactions between humans. Stephens, Silbert, and Hasson [29] conducted a groundbreaking experiment in which speaker/listener dyads were monitored simultaneously using functional magnetic resonance imaging (fMRI) to assess neural synchronies between individuals under varied conditions of story comprehension. The results not only provided evidence for detectable spatial and temporal neural coupling in which the listener’s brain activity mirrors the speaker’s, but also demonstrated that the extent of coupling correlated to the level of story comprehension, and demonstrated that this synchronization ceases under conditions of poor comprehension. During high levels of comprehension, the listeners exhibited predictive anticipatory patterns, with greater the anticipatory speaker–listener coupling corresponding to greater understanding. Stephens and his colleagues argue that this synchronization between production and comprehension-based processes serves as a mechanism by which brains convey information [29], and assert that in many cases the neural processes between brains are coupled, leading to complex synchronized behaviors which must be studied in combination, rather than in isolation in order to be understood [30]. Such brain-to-brain coupling is particularly relevant within the context of dyads in which two humans must collaborate to complete joint tasks, as well as within the context of impartition of knowledge from one individual to another for the purposes of training. Under a current research effort, our team is investigating the use of EEG-based cognitive coupling metrics for an expert/tutor teaching a novice/tutee to complete a complex computer-based task.

3.2 Team Neurodynamics

Recent studies have also shown tremendous promise for the development of EEG-based measures of team cognitive dynamics. For example, Stevens, Galloway, Berka, and Sprang [31] modeled changes in EEG-derived measures of cognitive workload, engagement, and distraction, and explored using neurophysiologic collaboration patterns as an approach for developing a deeper understanding of how teams collaborate when solving time-critical, complex real-world problems. The resulting cognitive teamwork patterns, termed neural synchronies, were different across six different teams. Stevens, Galloway, Berka, and Behenman [32] suggest that neural synchrony expression may be a reflection of the internal state of team members and of the team as a whole. These studies indicate that non-random patterns of neurophysiologic synchronies can be observed across teams and members of a team when they are engaged in problem solving. This process has been applied to a problem-solving task with students working in teams, as well as navy officers (experts) and officers-in-training (novices) completing a submarine navigation task. Distinct differences were found for expert versus novice neurodynamic synchronies, and novice team neural synchrony metrics were shown to improve (become more like the expert team patterns) over time, providing a potential metric for knowledge and skill acquisition. Furthermore, dynamic detection and classification of individual cognitive states as they relate to team neurocognitive dynamics and performance could be used to identify team members that are not in sync in real time, alerting team leaders to potential underperformance and poor communication in order to support mitigation of team performance degradation via technology-based and interpersonal interventions. This paradigm could be applied across teams of individuals that are both co-located and remotely located, and may in fact provide the most benefit to teams of individuals collaborating over distances in which critical communication elements such as nonverbal cues cannot be relied upon. A vast variety of critical team interaction domains ranging from military operations to surgical teams serve to benefit from such a paradigm.

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